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BROADBAND MICROSTRIP MATCHING TECHNIQUES

D. A. Paschen
Ball Aerospace Systems Division
Boulder, CO 80306

ABSTRACT

Microstrip antennas are used in many applications where a low-profile conformal antenna is desired. They are rugged, lightweight, and easily fabricated. However, it is desirable to increase the bandwidth of these antennas. Through the use of proper matching techniques, standard microstrip antennas can be matched to bandwidths of 35% or more. A rectangular half-wave microstrip radiator was built and tested with and without broadbanding to show the capabilities of these matching techniques.

1. INTRODUCTION

Microstrip antennas are found in a wide variety of applications from wraparound missile telemetry antennas to spaceborne SAR's to monolithic phased arrays. Many systems which could profit from the use of these radiators employ other types of elements due to the requirement for more bandwidth. The use of broadband matching techniques discussed in this paper will allow a greater number of systems to utilize the microstrip antenna.

2. LUMPED ELEMENT MATCHING

A lumped element bandpass filter is shown in Figure 1. The load impedance R_L is matched to the input impedance Z_{IN} over the passband of the filter. The bandpass filter can be designed to have either a wide or narrow passband depending on the number of sections and the component values. A microstrip antenna has an input impedance which can be modeled by the values R_L, C_L, L_L, and sometimes L_2. The remaining values can be chosen so that R_L is matched to Z_{IN} over the passband of the circuit. However, since the first few values are determined by the antenna input impedance, the bandwidth of the filter/matching network - although it is an improvement over the antenna alone - is limited.

The improvement in 2:1 VSWR bandwidth that can be obtained by matching depends on the number of resonators added. Table 1 gives the approximate improvement in the 2:1 VSWR bandwidth for a given number of lossless resonant sections added. It is apparent that

Filter Order (N)[2]	Bandwidth Improvement
2	2.33
3	2.84
4	3.18
∞	3.86

Table 1. Bandwidth Improvement Versus Filter Order for 2:1 VSWR Bandwidth.

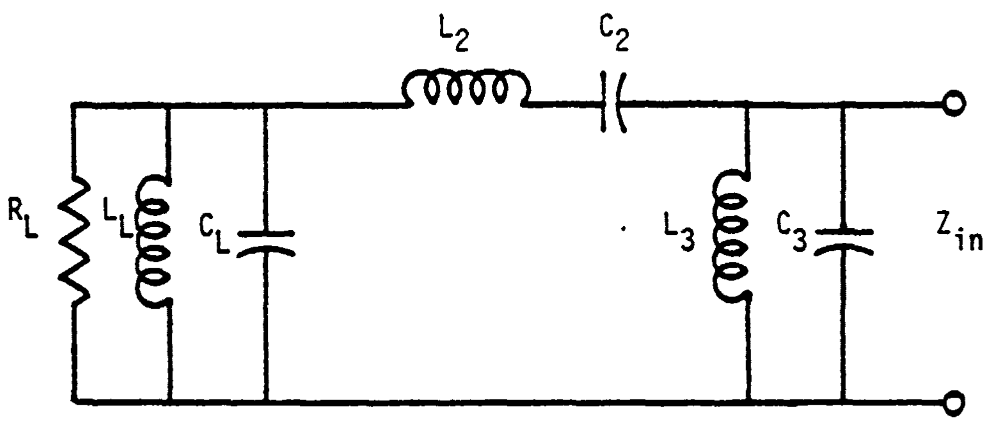

Figure 1. Lumped Element Bandpass Filter

the addition of more than three resonant sections would rarely be needed due to diminishing improvement in bandwidth. In addition, the loss in the matching network will increase with the number of sections added, thereby reducing the overall gain of the antenna element.

The values of the components in the filter can easily be determined. The graphs in Figures 2 and 3 show the maximum insertion loss and passband ripple versus the decrement(s) and the graphs in Figures 4-6 show the element values versus decrement.[3] The decrement is the ratio of the Q of the signal to the Q of the load impedance. It can be most easily calculated in the microstrip case by taking the ratio of the real part of the impedance/admittance at the band edge to the imaginary part of the impedance/admittance depending on whether the load is series or shunt resonate. The decrement for any chosen or desired band edge can be calculated in this manner as long as the impedance is symmetric about the real axis. The "g" values found in Figures 4-6 can be used to calculate the inductance and capacitance of each resonant section. A low pass filter is designed first and each component in the low pass filter is resonated at the center of the bandpass filter. An example is given in Equations 1-7 for a third order matching network with a shunt resonant load (as in the case of a thin microstrip patch).

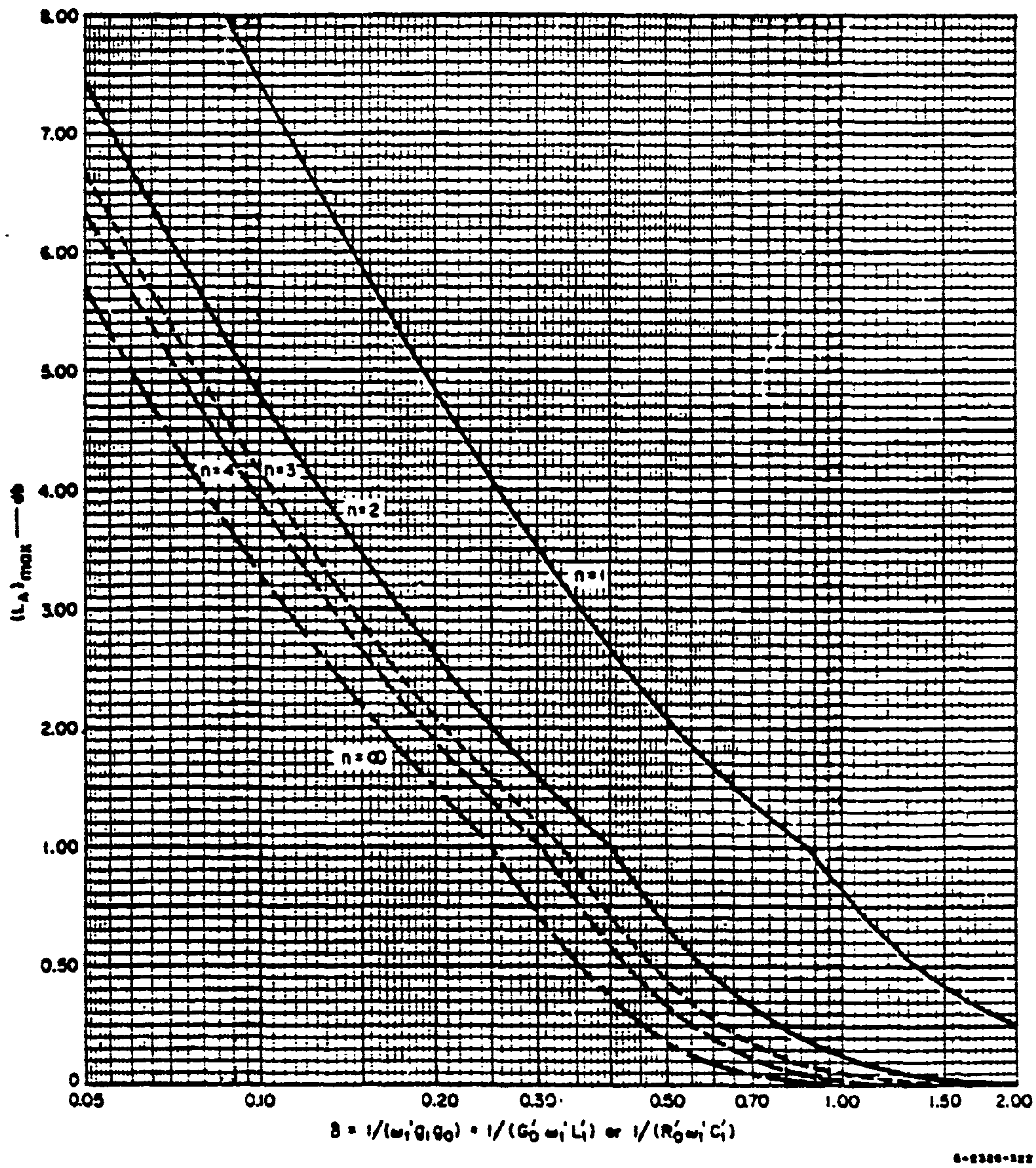

Figure 2. Maximum Insertion Loss Versus Decrement[3]

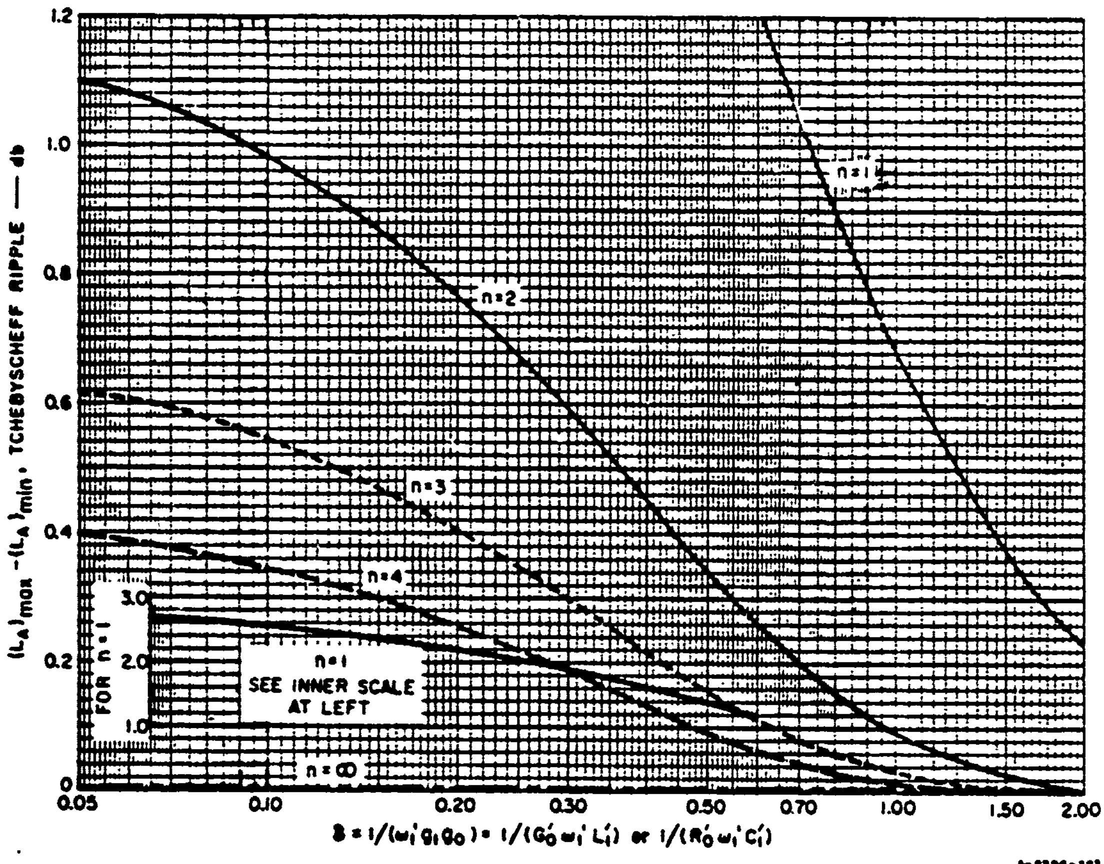

Figure 3. Passband Ripple Versus Decrement[3]

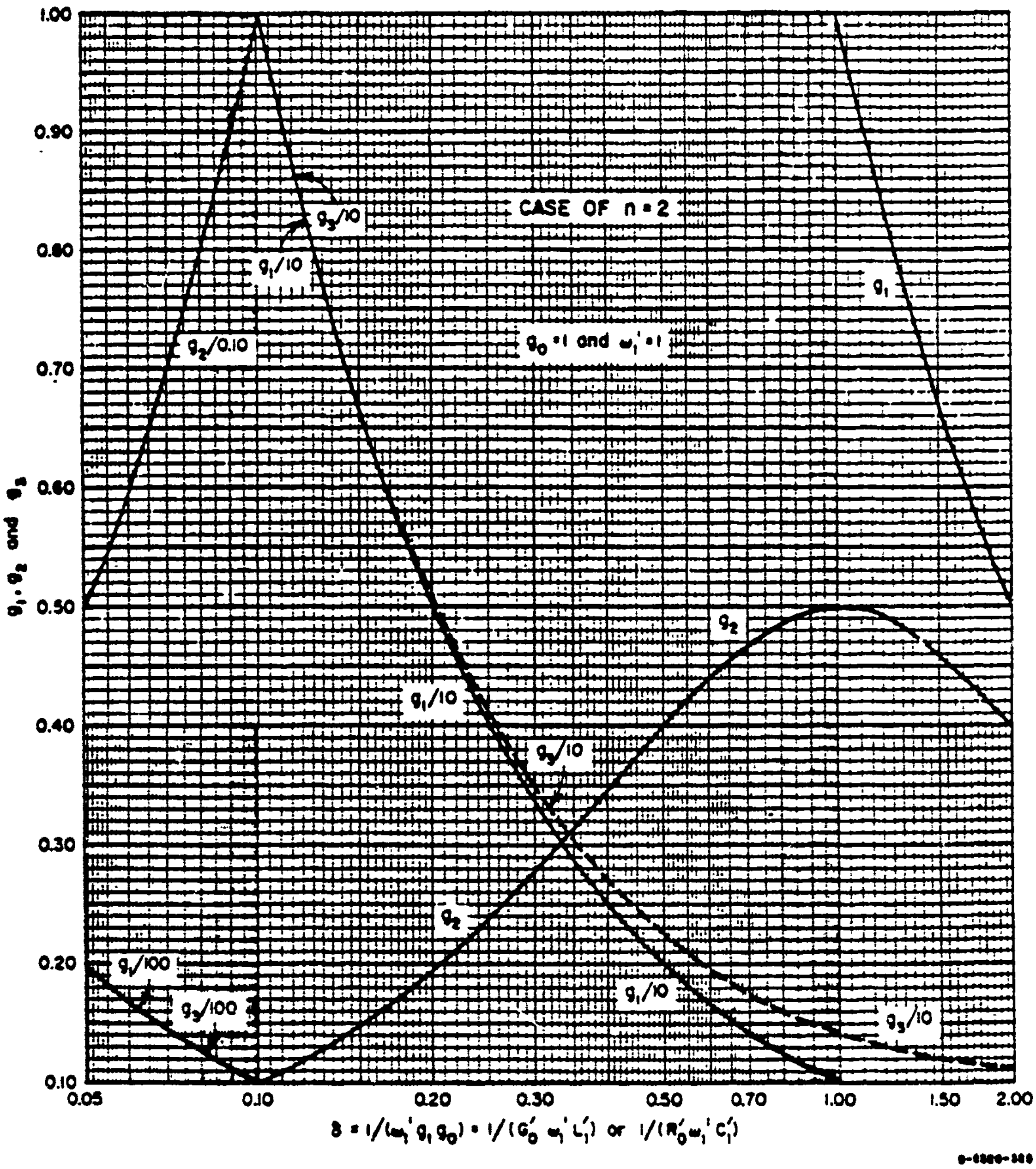

Figure 4. Element Values Versus δ for $N = 2^3$

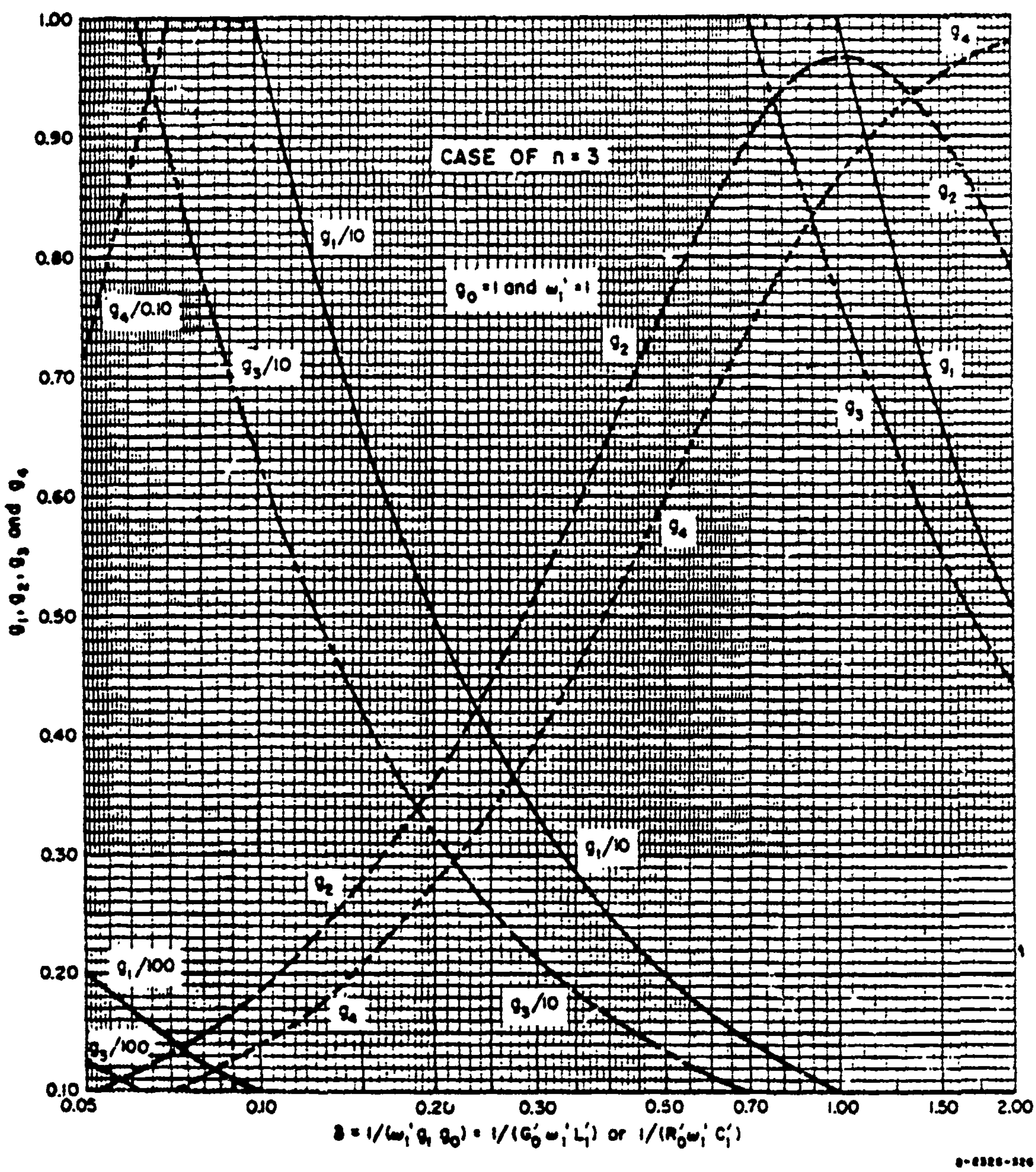

Figure 5. Element Values Versus δ for N = 3[3]

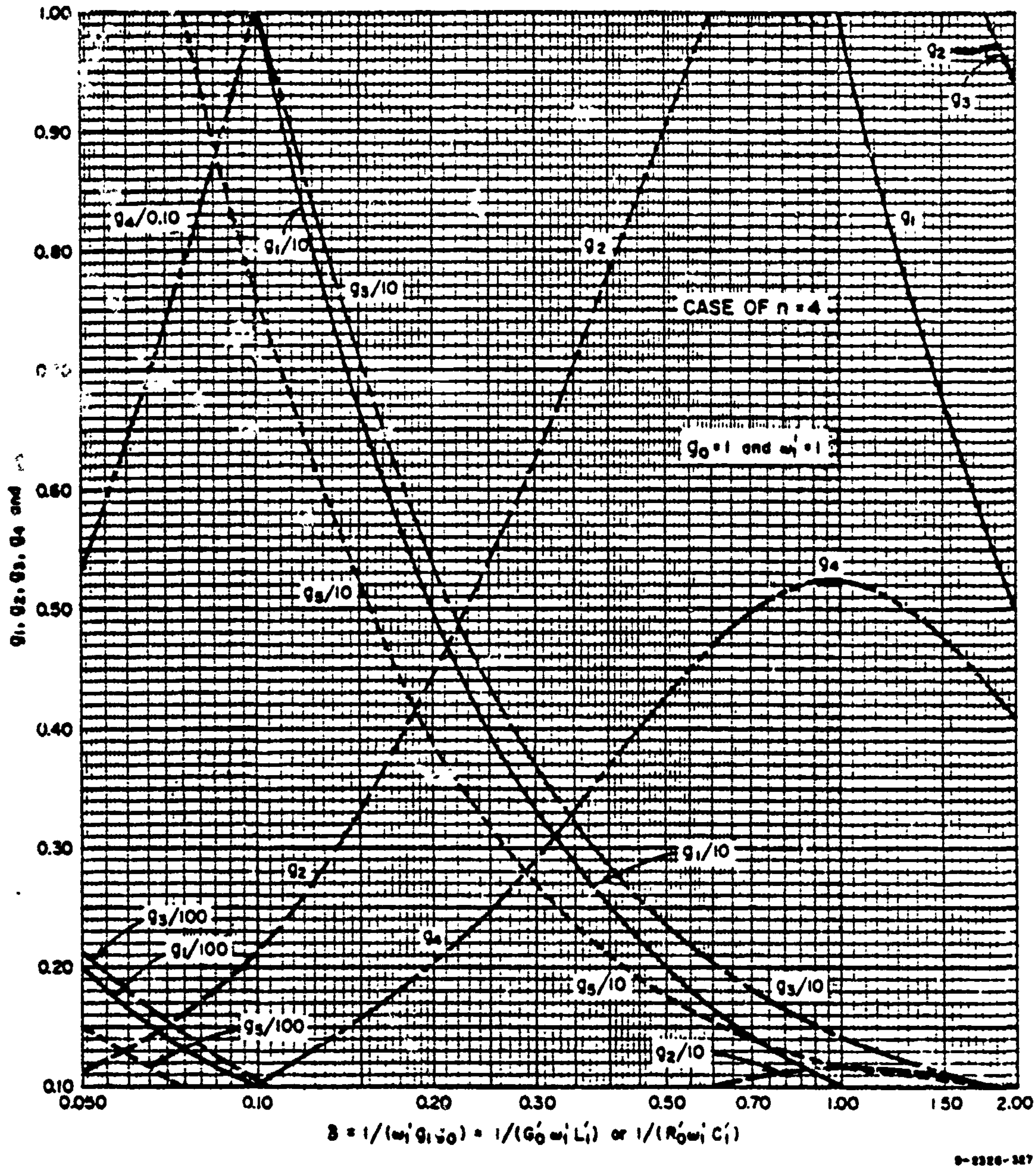

Figure 6. Element Values Versus δ for N=4 [3]

$$C_L = \frac{g_1}{R_L(\omega_2-\omega_1)} \tag{1}$$

$$L_L = \frac{1}{\omega_o^2 C_L} \tag{2}$$

$$L_2 = \frac{g_2 R_L}{\omega_2-\omega_1} \tag{3}$$

$$C_2 = \frac{1}{\omega_o^2 L_2} \tag{4}$$

$$C_3 = \frac{g_3}{R_L(\omega_2-\omega_1)} \tag{5}$$

$$L_3 = \frac{1}{\omega_o^2 C_3} \tag{6}$$

$$R_{IN} = g_4 R_L \tag{7}$$

It is important to note the impedance transforming property of the matching network in Equation 7. The values in Equations 1 and 2 are simply a model of the load impedance and are not part of the matching network. The example given would be expected to improve the 2:1 VSWR bandwidth of the antenna by a factor of 2.84 as shown in Table 1.

This technique requires a symmetric distribution of the impedance around the real axis. In order to design a match for thick patches,

which usually fall towards the inductive side of the Smith chart, it is necessary to either model the impedance to determine L_2 in the circuit in Figure 1 or add a section of transmission line of the appropriate length to rotate the impedance until it is symmetric about the real axis.

3. DISTRIBUTED MATCHING

At frequencies where lumped components are not easily fabricated or where the size of a distributed network is reasonable, it is possible to design a transmission line matching network which will provide similar results to the lumped element network. The series and shunt resonators in the lumped element circuit can be replaced by series and shunt stubs. Figure 7 shows two versions of this type of filter - one with quarterwave stubs and one with half wave stubs. The impedance of each stub can be calculated to give essentially the same reactance slope as the lumped element resonators; however, series stubs are difficult to implement in stripline and microstrip. In these cases a shunt stub with quarter wave section on both sides will approximate a series stub over moderate bandwidths. The quarterwave transformers on each side give additional degrees of freedom to allow the resonant impedance of the patch to vary from the value R_{IN}/g_{N+1} which would be desired in the lumped element circuit.

In the distributed matching network, one of the best means for determining the component values is through the use of an optimization routine. This allows full use of the extra freedom obtained by using quarterwave transformers between shunt resonators. The number of shunt stubs is equal to the number of resonant sections desired. Figure 8 shows an example of a third order matching network for a series resonant load.

4. DESIGN OF A BROADBAND MICROSTRIP ELEMENT

In order to demonstrate the possibilities of broadband microstrip matching, a rectangular microstrip patch was constructed with a 2:1 VSWR bandwidth goal of 20%. The halfwave element was built on one-quarter inch honeycomb to operate at a center frequency of 3 GHz. The bandwidth of the element when fed in the normal manner was 7.17%. Figure 9 shows the impedance of this element.

A matching network was then designed based on the preceding discussion and optimized using a program written by the author. The matching network was designed to be placed on a separate layer directly beneath the element. Figure 10 shows the topology of the matching network. The input impedance of the broadbanded element is shown in Figure 11. The 2:1 VSWR bandwidth of the element with matching network is 20.29%; this is almost exactly the predicted improvement of 20.36% for a third order network. In order to show that the loss in the matching network was not responsible for the gain improvement and that it was small swept gain measurements that were made on the element before and after broadbanding. The results are shown in Figures 12 and 13. It is apparent from the swept gain measurements that the center frequency of the element and matching network are slightly off; however, the results indicate that the bandwidth of a resonant antenna such as a microstrip patch can be increased with the techniques described in this paper.

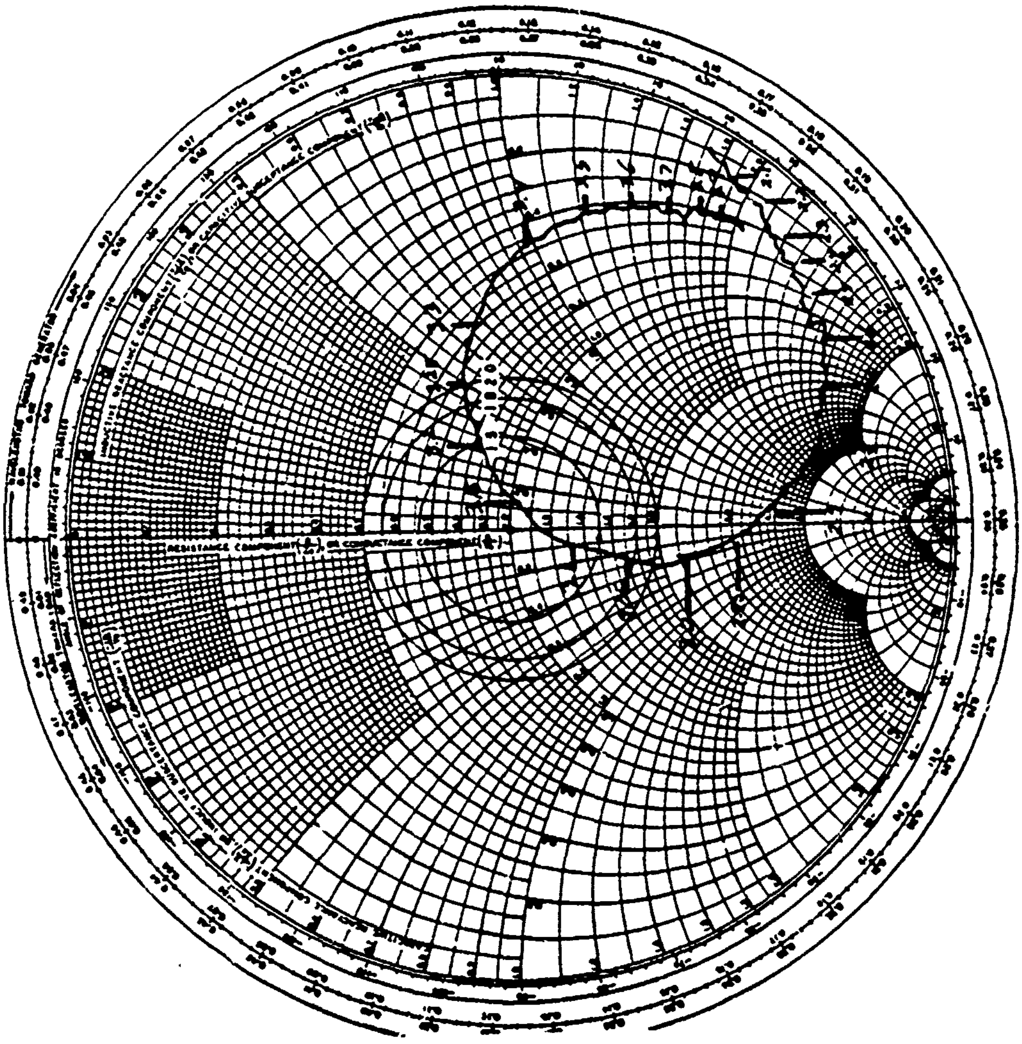

Figure 9. Input Impedance of Resonant Microstrip Antenna

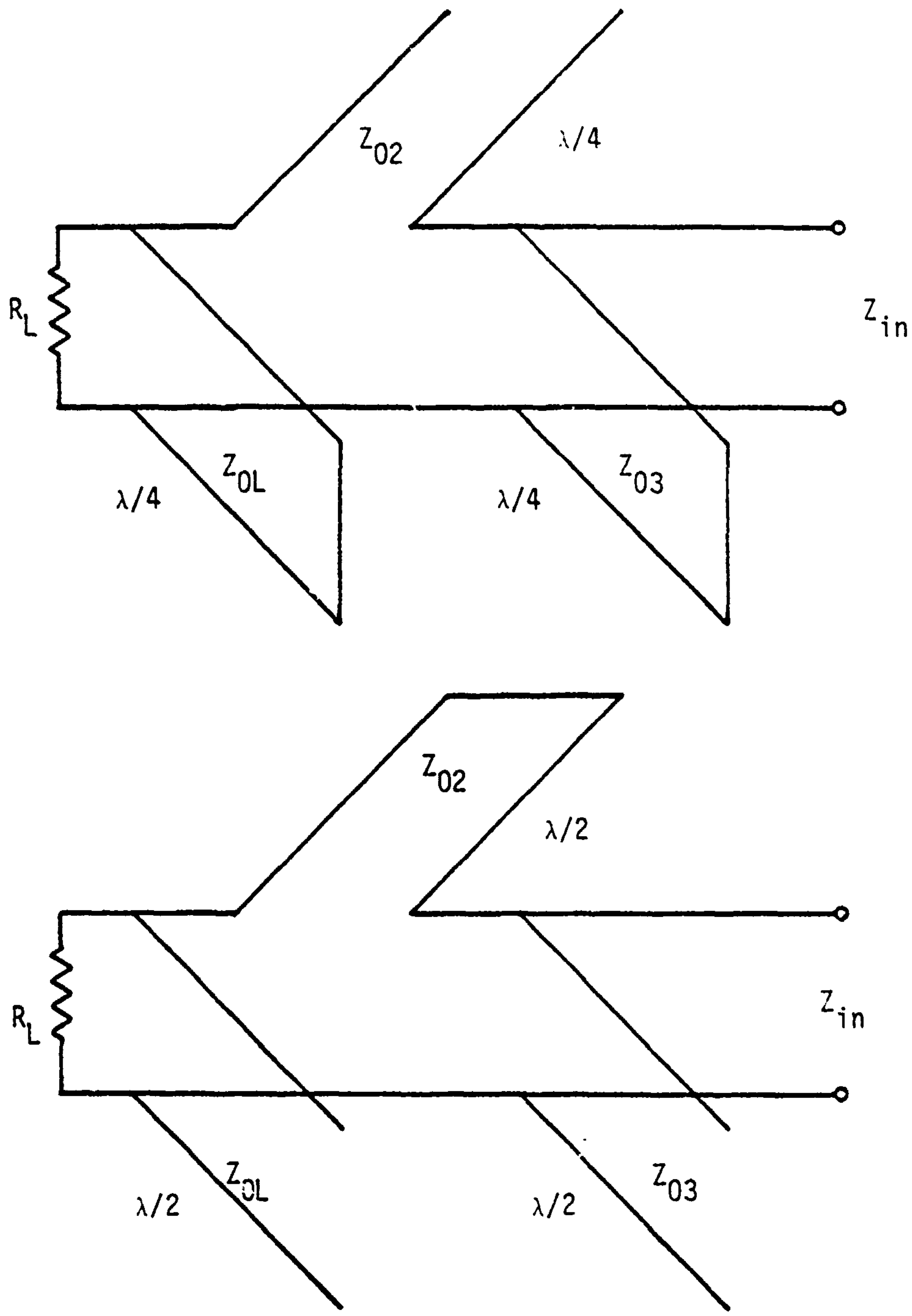

Figure 7. Distributed Matching Networks for N=3

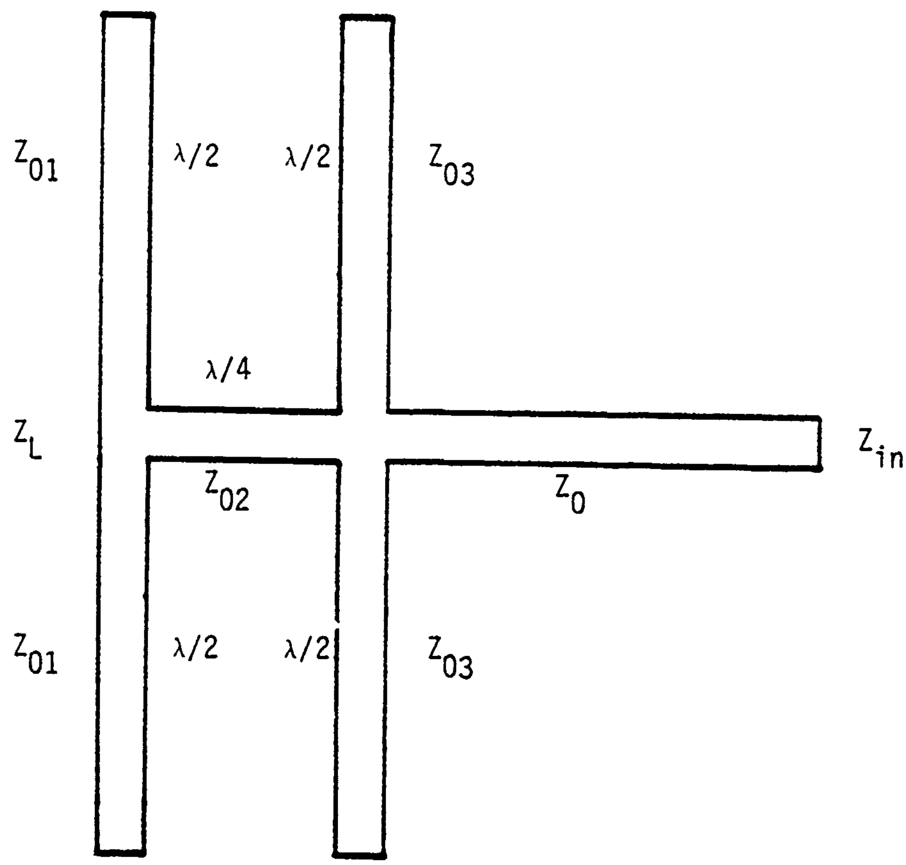

Figure 8. Microstrip Matching Network for N=3

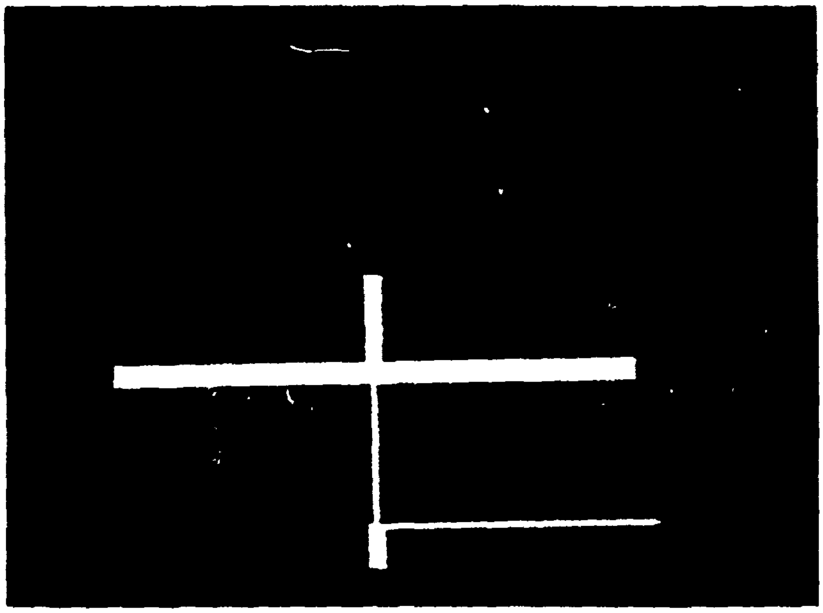

Figure 10. Matching Network Topology

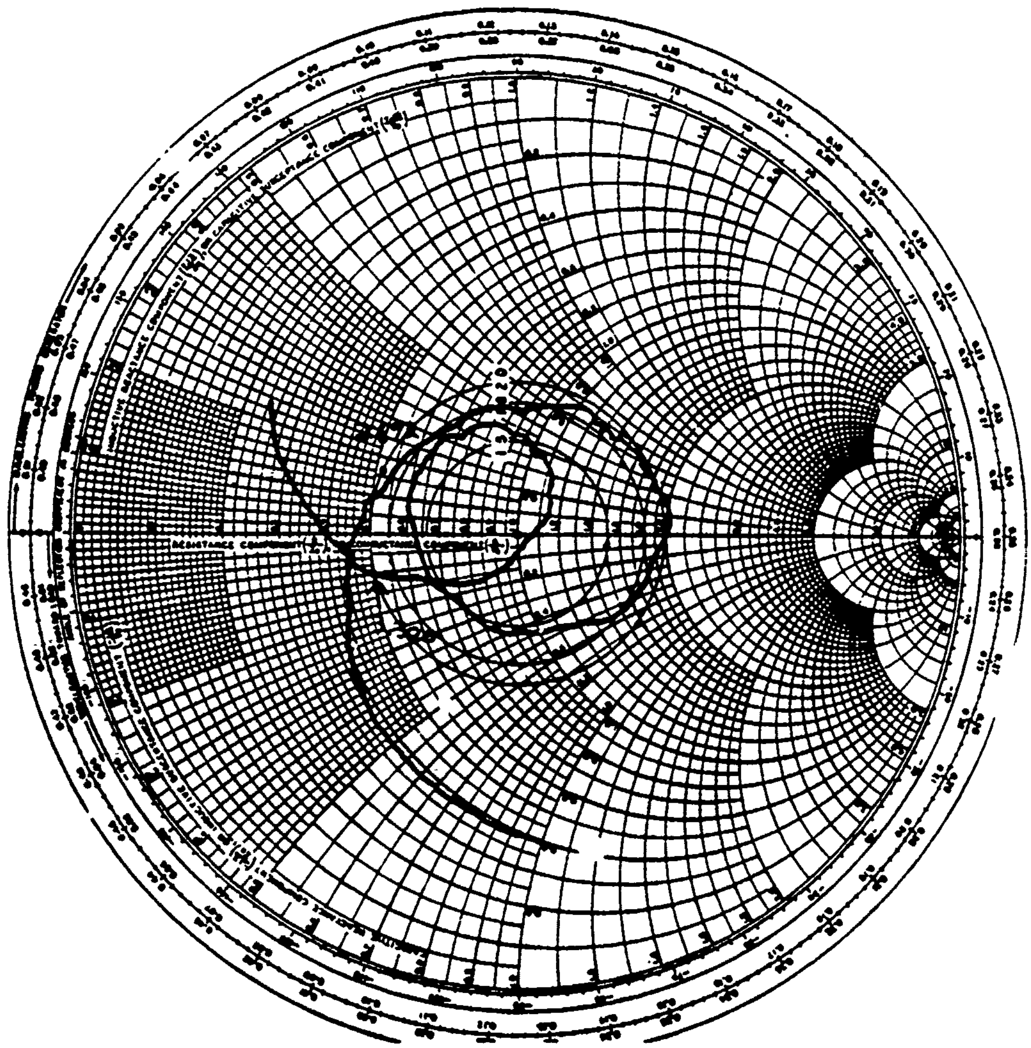

Figure 11. Input Impedance of Broadbanded Microstrip Antenna

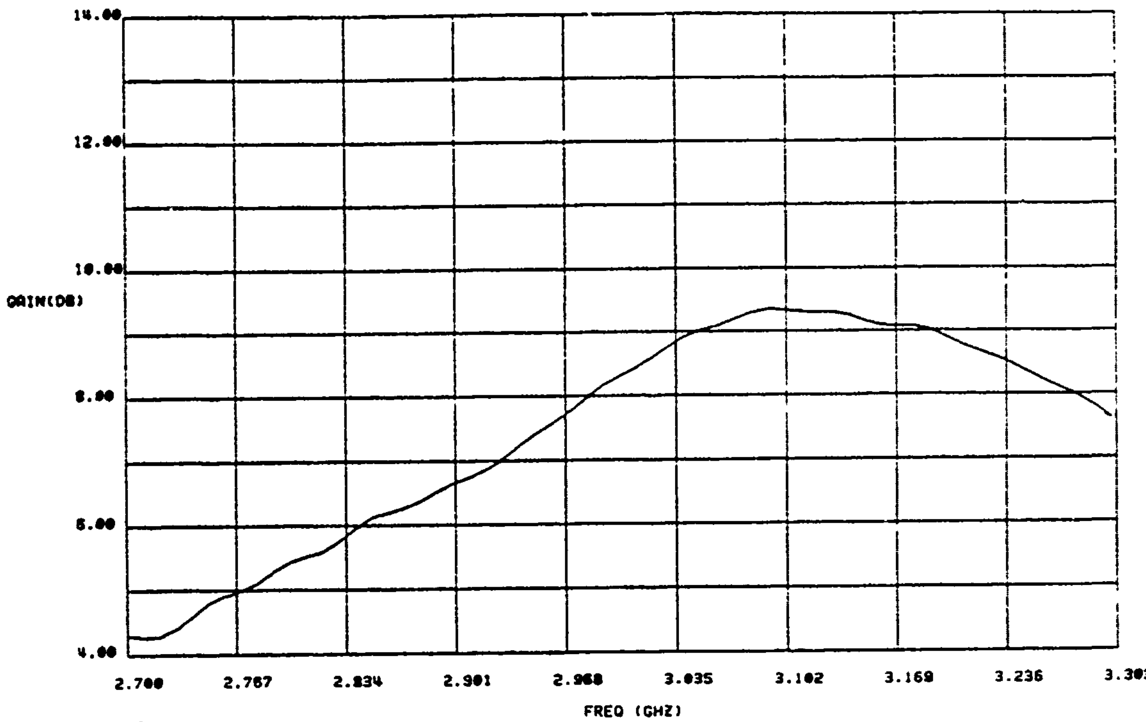

Figure 12. Gain of Resonant Microstrip Antenna

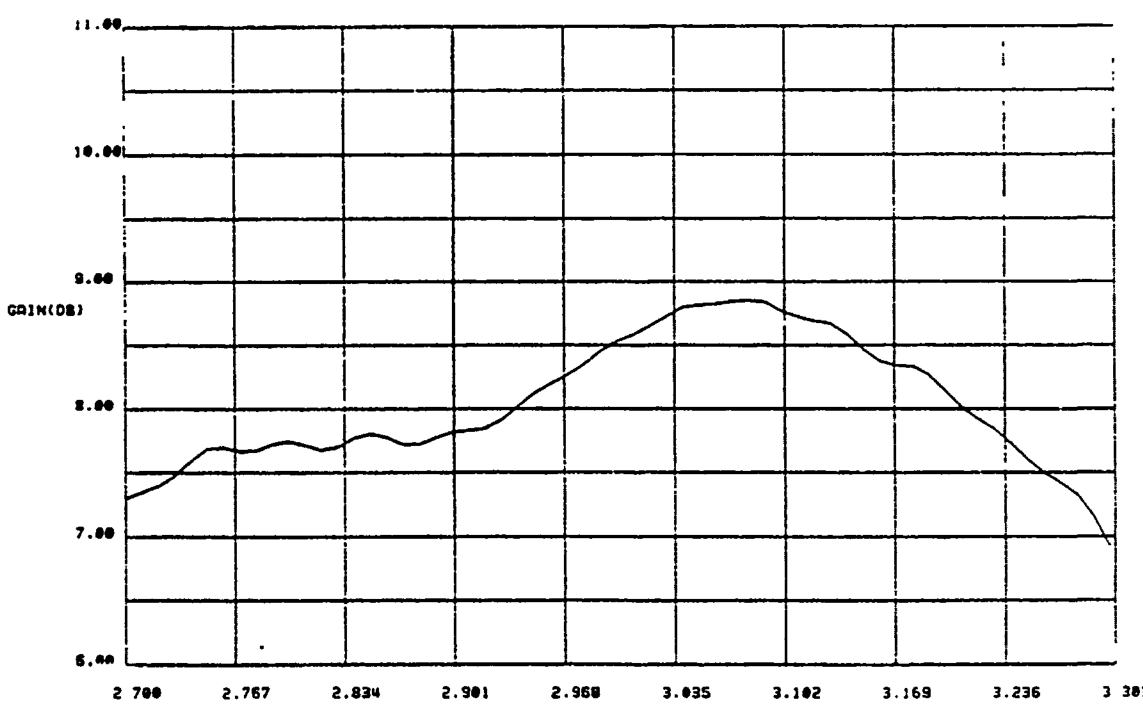

Figure 13. Gain of Broadbanded Microstrip Antenna

5. CONCLUSIONS

The microstrip antenna should find new and expanded application through the use of broadband matching techniques. In systems where the construction of narrow bandwidth microstrip elements places an extreme demand on fabrication tolerances, the use of broadband matching may reduce system costs by relaxing those tolerances. The potential for greater than 35% bandwidth should allow the microstrip antenna to find use in EW systems where several elements can be used to cover greater bandwidths and where the low cost conformal nature of the microstrip antenna would be an advantage.

ACKNOWLEDGMENT

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REFERENCES

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2. The filter order (N) is equal to the number of added resonators plus one, since the antenna is the first resonant section.
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